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The effect of elevated temperatures on the properties of cold-drawn steel fibres

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This study aims to evaluate the effect of elevated temperatures on the physical, mechanical and microstructural properties of a hooked-end steel fibre for temperatures of 100, 350, 750 and 1000°C. Results show that an oxidation layer is formed on the surface of the fibres exposed to temperatures of 750°C and above, which leads to an increase in external diameter and mass. Reductions in tensile strength are directly proportional to the temperature increase, while rupture strain values significantly increase for temperatures above the recrystallisation temperature of steel. This study contributes to the understanding of the contribution of steel fibres to the overall behaviour of the composite after temperature exposure and serves as an input for recently developed numerical models.

Introduction

The vast majority of applications of steel fibre-reinforced concrete (SFRC) are related to infrastructure elements, such as pavements, tunnels and sanitary pipes (Borges *et al.*, 2019; de Figueiredo, 2011; de la Fuente *et al.*, 2012). Steel fibre-reinforced concrete is successfully used in civil engineering as a total or partial replacement of conventionally reinforced concrete (di Prisco *et al.*, 2010; fib, 2013). In this context, evaluation of the post-crack behaviour of fibre-reinforced concrete is essential to ensure the safety of structures built with this composite, especially after fire events.

During a fire event, a wide range of temperatures is generated in the composite, which results in changes in three main aspects: the physical and mechanical properties of the cementitious matrix (Chen *et al.*, 2014; Düğenci *et al.*, 2015; Tai *et al.*, 2011; Zheng *et al.*, 2012), the properties of the reinforcing fibres (Serafini *et al.*, 2019), and the properties of the fibre–matrix interface (Abdallah *et al.*, 2017a, 2017b; Ruano *et al.*, 2018). The fibres play an important role in bridging microscopic and macroscopic cracks in order to prevent unstable crack growth and delay crack opening (Banthia, 1994); therefore, characterisation of their properties after heat exposure is of paramount importance. The physical and mechanical properties of steel are affected by temperature, since the steel oxidises, microstructure recrystallisation occurs and the steel grain size changes (Callister and Rethwisch, 2007; Chen and Yuen, 2003; Shackelford and Alexander, 2001).

The high-temperature oxidation of steel is driven by the reaction between the metal and atmospheric oxygen at elevated temperatures. This corrosive process especially occurs at temperatures of 700 to 1250°C and forms a friable three-layered scale structure (Chen and Yuen, 2003). The formation of this scale structure may significantly affect the cross-sectional area of steel fibres and reduce their tensile strength. The recrystallisation process consists of the formation of a new set of strain-free grains; this reduces the strength and hardness of steel, while increasing ductility (Callister and Rethwisch, 2007). After these new grains are formed, they begin to grow in size and the reduction in grain boundary density results in tensile strength reductions. Although all these metal-related processes are well defined in the literature (Shackelford and Alexander, 2001), the outcomes of these processes have not yet been quantified for steel fibres.

Considering these effects, the objective of this study is to evaluate the physical and mechanical properties of cold-drawn hooked-end steel fibres after exposure to elevated temperatures. Changes in terms of external diameter, mass and length were evaluated as a function of temperature and the tensile strength of steel fibres was determined using direct tensile strength tests. The effective cross-sectional area of steel fibres was determined by optical microscopy, and the steel grain size was determined by scanning electron microscopy (SEM). Additionally, the mineralogical composition of the oxide layer formed was characterised by X-ray diffraction (XRD). This research paper provides valuable data to explain the behaviour of SFRC after exposure to elevated temperatures and provides results that are of great value for the parameterisation of numerical modelling where the characteristics of the fibres are relevant in their implementation (Bitencourt *et al.*, 2019). Therefore, the residual capacity of SFRC structures can be assessed by designers using numerical simulation based, in part, on the conclusions of this paper.